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AVIATION CLOCK DIAL CHARACTERISTICS IN RELATION TO SPEED AND ACCURACY OF READING

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AVIATION CLOCK DIAL CHARACTERISTICS IN RELATION TO SPEED AND ACCURACY OF READING

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CHAPTER I

INTRODUCTION

I. STATEMENT OF THE PROBLEM

This is the report of an investigation of aviation clock dial design in relation to speed and accuracy of reading. The purpose was to compare different dial designs for speed and accuracy of reading in the twenty-four hour system. Further, it was desired to determine which design characteristics contributed to efficiency of reading.

Specifically, the problem developed into speed and accuracy comparisons of four dial designs. One was the conventional twelve hour design. Another was a twenty-four hour design. The other two were original variations of a counter-pointer design wherein the hour appears on a counter on the face of the dial and the minutes and seconds are indicated by hands.

II. DISCUSSION OF THE PROBLEM

That more attention has not been devoted to clock dials is unfortunate. It is a fact that in spite of the many recent improvements in military aircraft instruments little has been done to improve clock dials. The simple, old fashioned clocks are frequently read in error. This error sometimes amounts to as much as twelve hours because the human element has been neglected in making legible dial designs. Dial designs have failed to keep abreast of current military timekeeping practice. Military time-keeping avoids the confusing duplicity of readings and the notations of AM or PM, by recording time on a twenty-four hour basis starting and ending at midnight. The application of this system to the conventional twelve hour clock dial design requires that all PM readings be converted to the twenty-four hour basis by the addition of twelve hours. This is usually performed mentally and, therefore, is subject to the errors probable in all mental calculations. Further, the dial is composed of not one but two separate scales which must be visually and mentally separated, interpreted and finally integrated to arrive at the correct reading. One is the hour scale from one through twelve. The other is the minute and second scale from one through sixty. Indications on these scales are provided by three separate indicators or hands; the hour hand, the minute hand, and the second hand. However, while the minute and second hands provide their indication directly by pointing at the appropriate division of the scale, the hour hand provides its indication by its relative position with respect to the two nearest numbers. This also leads to confusion and error.

The situation is further confused by the fact that the aircrew members, particularly the pilot, have many other dials, switches, levers, indicators, and controls which demand a share of their attention. Relatively speaking, the clock dial plays a minor role in the complex physical, mental and visual processes in which they are engaged. However, a substantial error in the determination of time will, under certain circumstances, be of serious consequence if allowed to remain undetected. In this respect, there is likely to be a vast difference between a man noting the time of day on a clock in his home or automobile, and the same man noting the time of day while a member of an aircrew. In the first case he may arrive too early or too late for a social engagement, but generally the damage will not be serious. In the second case, a miscalculation could be, and certainly has been, so serious as to be fatal. Nor is it always necessary that the error be one of great magnitude to have serious consequences. Errors of a few minutes to less than one minute are equally, and in some circumstances, more hazardous than large errors. It is a peculiar fact, too, that rapid and accurate time reading is most desirable when operating under unfavorable conditions, such as when on instruments or in combat. It is during these stress conditions that the overall attention demands of the crewmembers job are the greatest.

In general, aircrew members use a clock in three different ways. Most frequently the method of reading the clock is to check read it. In this case the time is not noted as being a specific and exact value, but is noted as being prior to or subsequent to a specified time. An example here is the situation where a pilot anticipates receiving the weather broadcast from the nearest radio range facility. He knows that the broadcast starts at twenty-nine minutes after the hour, and a check of his clock assures him that the present time is prior or subsequent to that time. There is no attempt to pin-point the time. If, as is frequently the case, the duties of the pilot at this moment are so great that the demand upon his visual, mental, and physical reactions is at a maximum, then it is helpful to have an instrument that can be read rapidly and accurately.

Another method is to read the time accurately and completely. Frequently a value for seconds is included. This method is useful for the determination of such things as fuel consumption, ground speed, or elapsed time.

Finally, the minute and or second hand(s) are used alone for the determination of short periods of elapsed time. One important application of this method is the instrument approach procedure. Since the pilot knows the time required to fly from the range station to the field, at his groundspeed, he can determine when he is over the field by timing his flight from the range station to the field in minutes and or seconds. As previously mentioned, the major portion of his attention will be devoted to the manipulation of the aircraft through the interpretation of his flight instruments and radio signals. It should be apparent then, that he will have to read the clock frequently, rapidly and accurately.

Any improvement in clock dial design that will facilitate rapid, accurate interpretation would be a factor in reducing the complexity of the pilot's duties and should thereby reduce the accident hazard. This, of course, is not a new fact. It has been previously recognized by pilots and by researchers in the instrument design field.

CHAPTER II

REVIEW OF THE LITERATURE

I. CLOCK DIALS

The problem of rapid and accurate time reading on a twenty-four hour basis, has been recognized by pilots and experimenters. It is equally true that very little attention and effort has been specifically devoted to the development of improved clock dial designs.

The only study of clock dial design in relation to speed and accuracy of reading in the twenty-four hour system that has come to the attention of this investigator was a study conducted in 1946 by Dr. W. F. Grether of the Psychology Branch, Aero Medical Laboratory, US Air Force.[1] As a matter of fact, Dr. Grether's study provided the inspiration for this investigation. This work could be viewed as an extension of his original study and an adaptation of some results obtained by him in an investigation of another instrument dial.

In his investigation of aviation clock dial design characteristics, Grether used eleven different dial designs.

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[1] W. F. Grether, Designing Clock Dials for Greatest Speed and Accuracy of Reading in the Military (24 hour) Time System, USAF Aero Medical Laboratory Memorandum Reports, #694-8, 21 October 1946, 16pp.

He made a comparison of certain design details to determine whether the twenty-four hour dials were more easily read in the twenty-four hour system than were the twelve hour dials. The design details investigated by him were:

a. The use of numerals versus no numerals on the minute scale.
b. The use of one minute versus five minute graduations on the minute scale.
c. The use of numerals at all hourly positions versus replacement of some numerals with reference marks.
d. The addition of a thirteen to twenty-four hour scale to the twelve hour scale versus no such addition.
e. The placement of the twenty-four hour position at the top versus the bottom of a twenty-four hour dial.
f. The placement of the sixty minute position at the top versus the bottom of a twenty-four hour dial.

Grether reports that the eleven designs, consisting of five variations of twelve hour dials and six variations of twenty-four hour dials, were prepared as mockups and were photographed with the hands in different positions to make up the actual items of a printed test. The test was then administered in two parts to sixty-two rated Air Force officers and to one-hundred high school students. Part one of the test consisted of ten settings of each dial design printed in an irregular sequence so that the subject was required to change from one dial type to another as he worked on the successive items of the test. Part two of the test was composed of ten settings of each dial type presented successively. Part one was scored on the basis of errors only, while part two was scored on the basis of errors and time. The data was then examined statistically and certain conclusions reached with respect to the objectives of the test.

With respect to the main objective of the test, the comparison of twelve hours versus twenty-four hour dials, Grether states that there is no major advantage in favor of either the twelve or the twenty-four hour dials used, although two types of his twenty-four hour dials were superior to the two best twelve hour dials. This was especially true for speed of reading. The twenty-four hour dials also showed somewhat more one hour errors.

With respect to the other test objectives, the following conclusions were reached by Grether:

a. There was no significant advantage in placing numerals on the minute scale of the twelve hour dial. However, the minute scale numerals seemed to be advantageous on the twenty-four hour dials used.
b. There is a significant difference in favor of placing graduations at one minute intervals.
c. Dials with numbers at all hourly intervals were more accurate than those which omitted some hourly numerals.
d. The addition of a thirteen to twenty-four hour scale on a standard twelve hour dial reduces accuracy.
e. A dial with the twenty-four hour position at the top was best in part one of the test while a dial with the twenty-four hour position at the bottom was best in part two of the test. The inference drawn here was that in a situation where an individual can become accustomed to reading a particular clock design, there is some advantage in placing the twenty-four hour position at the bottom of the dial.

f. Placement of the sixty minute position at the bottom of the dial caused a high percentage of errors.

Grether's report, unfortunately, fails to specify certain details of the test which have a bearing on the interpretation of the data. Specifically, no mention was made of the diameter of the dials used in the test. Kappauf[2] says that errors are less frequent for the larger and more finely graduated dials. The test probably consisted of dials of one size only; however, it is conceivable that the relative difficulty of reading two dials will not vary in equal proportion to their size. Thus, a complicated dial design, when reduced in size, may decrease in readability more than a simple design similarly reduced in size.

Furthermore, Grether failed to mention the color of the dial hands, numerals, markings, and background. The book, Lectures on Men and Machines,[3] states in reference to legibility of dials:

> If black numbers are used on a white background, the letters have to be about twice as thick. In general, white letters on a black background are more legible than black letters on white.

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[2] William E. Kappauf, Design of Instrument Dials for Maximum Legibility: I. Development of Methodology and some Preliminary Results, USAF Aero Medical Laboratory Memorandum Reports, #TSEAA-694-IL, 20 October, 1947, p.39.

[3] Lectures on Men and Machines, Number 166-1-19, Systems Research Laboratory, Johns Hopkins University, Baltimore, Maryland, 1947, p.207.

The size, shape, and design of numerals, hands and markings was not specified. Kappauf[4] notes that numeral design may be responsible for certain dial reading errors.

No explanation was advanced for the exclusion of the normally present second hand. Presumably, the difficulties of properly representing the moving second hand in such a static situation as a printed test prevented its inclusion. The fact that the exclusion was consistent tends to minimize its importance, yet, as in the case of size, there is no assurance that the exclusion of the second hands would have an equal effect on different designs. The only safe procedure would seem to be to include it.

Although it is explained that an attempt was made to control the average difficulty of reading of the items for all clocks, the exact hand settings were not specified. No information is available as to whether or not the ten settings for each dial type were identical or not. In this connection, Kappauf[5] observes that:

> Selecting different random sets of numbers for the settings to be used on different comparison dials is poor practice. This conclusion follows from the existence of marked differences in the reading difficulty of particular dial settings. Since the origin of all such specific difficulties cannot be determined in advance, allowance must be

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[4] Kappauf, op. cit., p.40.

[5] Kappauf, op. cit., p.41.

> made for them in planning experiments. Hence, where dial variables may be expected to produce relatively small differences in performance, the only safe procedure is to match settings for all comparisons or, if this be impossible because of the differences in the total scale values of the dials to be compared, to use all possible settings.

Part two of the test was stated to be ten settings of each dial presented successively, followed by ten settings of the second dial, and so on through the eleven designs. Presumably, the sequence of the eleven designs was the same throughout the second part of the test. If the presumption is correct, there is a possibility that the subject's reactions to one dial type were influenced in some degree by practice effects or by fatigue effects.

In connection with the administration of the test and the test subjects, there is no information regarding the visual abilities of the subject, the experience of the subject in reading time in the twenty-four hour system, the reading distance, the illumination, the test instructions or the test procedure.

The test was printed and the subjects were required to read the dial and to write the answers in the booklet. There is a possibility that some of the speed and some of the accuracy was influenced by the ability of the subject to rapidly and accurately write his interpretation of the dial reading. However, since all dials were tested in the same manner, the criticism of written responses is probably not serious or important.

Regarding the specific method of interpreting and recording readings, it would seem important to know whether the subject was required to read time in a specified manner, such as, for example, eight forty-five, or whether he was allowed to read as was customary with him which might be, in this example, fifteen minutes to nine. Certainly if he were forced to use an unfamiliar method, a degree of learning would be reflected in the results.

An explanation of the methods used in analyzing the data would seem to be in order. For example, in the analysis of errors, if a subject misread both the hour and the minute settings on any one presentation was he charged with one or two errors? Further, for both speed and accuracy data it would have been helpful had frequency distributions been included in the report.

II. OTHER DIALS

General statements regarding instrument dial design have been advanced by many investigators. A few of those studies that have a direct relationship to this investigation will be mentioned here.

Loucks[6] found in a tachistiscopic presentation of tachometer dials that:

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[6] Loucks, R. B., Legibility of Aircraft Instrument Dials: A Further Investigation of the Relative Legibility of Tachometer Dials. AAF School of Aviation Medicine, Randolph Field, Texas. Project #265, Oct., 27, 1944a.

1. Accuracy decreased as scale divisions increased.
2. Numbered subdivisions reduced accuracy.
3. The more simply a dial is designed the less difficulty there will be in reading.

The first two findings are directly opposed to findings by Grether.[7] However, it must be noted that Loucks presented the dial briefly. The subject was forced to read at an artificially rapid rate with no opportunity for a second glance if he thought such was necessary. Grether's subjects were allowed to set their own pace and they had the opportunity to check or recheck any doubtful reading. Such would normally be the case with an individual actually reading a clock. The third observation from Loucks regarding simplicity of design would seem to be entirely reasonable.

Sleight,[8] in an experiment to determine the relative legibility of five different shaped dials, reports that legibility of counter type dials was extremely high with round type dials being next in legibility. This report corroborates the experimental evidence reported in the book, Lectures on Men and Machines.[9]

In a general article on the subject of dial reading, Grether[10] stated that:

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[7] Grether, W. F., op. cit., p.2.

[8] Sleight, R. B., "The effect of Instrument Dial Shape on Legibility," Journal of Applied Psychology, 32:170, April 1948.

[9] Lectures on Men and Machines, op. cit., p. 215.

[10] Grether, W. G., "Instrument Misreading Seen Due to Misinterpretation - Not Poor Seeing," Society of Aeronautical Engineering Journal, 56:44, September, 1945.

1. Most errors are due to interpretation and not to legibility or acuity. Therefore, simplify presentation and interpretation.
2. Studies of quantitative readings of multi pointer instruments indicate:
   a. Combining readings from two or more pointers into a single quantitative reading is difficult and causes errors.
   b. A common error is reading too high by one revolution of the sensitive pointer.
   c. In combining of numbers from different pointers, numerous errors result from digits being displaced or interchanged in the number series.
   d. Misreading of the dial scale causes a high proportion of errors.
   e. Other types of errors occurring infrequently are:
      1. Omission of one pointer.
      2. Interchange of two pointers.
      3. Repetition of reading on one pointer.
      4. Reading to lower adjacent instead of to nearest numeral.
   f. Most of these types of errors are probably unavoidable in instruments that require the combining of readings from two or more pointers.
   g. All errors, except misreading of scale, can be virtually eliminated by the use of a single pointer instrument with a counter to indicate the number of revolutions of the pointer.

With the last principle mentioned above apparently in mind, Grether investigated the speed and accuracy of reading various altimeter dial designs.[11] Among the designs examined were the conventional three pointer

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[11]Grether, W. F. The Effect of Variations in Indicator Design upon Speed and Accuracy of Altitude Readings, USAF Aero Medical Laboratory Memorandum Reports, #694-14, 2 September 1947.

dial, a counter-pointer dial and a counter. He reports that the speed and accuracy of reading was greatest for the counter type with the counter-pointer type being only slightly inferior to the counter. Both were unquestionably superior to the conventional dial.

It was while reviewing the above report that the idea of applying the results to the problem presented by clock dials emerged. It seemed to offer an improvement over any of the eleven dials tested by Grether in his clock dial investigation. The design also was consistent with Grether's remarks regarding quantitative readings of multiple pointer instruments (2g above). Accordingly, a counter-pointer dial was designed for a clock and was used in this investigation as explained in the following chapter.

In addition to a review of the literature, several watch companies known to be sources of supply of clock dials for the United States Air Force were consulted to learn of recent activity of their engineering design departments with respect to twenty-four hour clock dials. The replies all indicated that none of the watch companies were engaged in any activities regarding the development of a twenty-four hour dial.

CHAPTER III

APPARATUS PROCEDURE AND SUBJECTS

I. GENERAL

As stated in a previous chapter, this investigation might be considered as an extension of Grether's research on clock dials. It is also, in part, a specific test of his thesis that a counter-pointer dial might be read more accurately and more rapidly than a multiple pointer type of dial. The purpose was to compare different dial designs for speed and accuracy of reading in the twenty-four hour system. Further, it was desired to determine which design characteristics contributed to efficiency of reading.

The study was undertaken by: (a) Careful design of the new dials to take advantage of known psychological facts. (b) Careful design of the test apparatus to insure proper control of those factors which were subject to stabilization. (c) Selection of a test procedure which would tend to minimize adverse test effects and which would maximize similarity with the actual conditions under which the dial was expected to be used. (d) Selection of test subjects from pilots and non-pilots. Specifically, non-pilot and military pilot subjects were selected from students in an engineering college. These subjects read, as rapidly and as accurately as possible, samples of all four dials.

Their speed and accuracy was recorded and these data form the basis for the conclusions reached.

This study makes no claim to being a completely exhaustive treatment of the subject. The writer is acutely aware that limitations of time prevented the exploration of many parallel lines of investigation.

II. THE DIALS

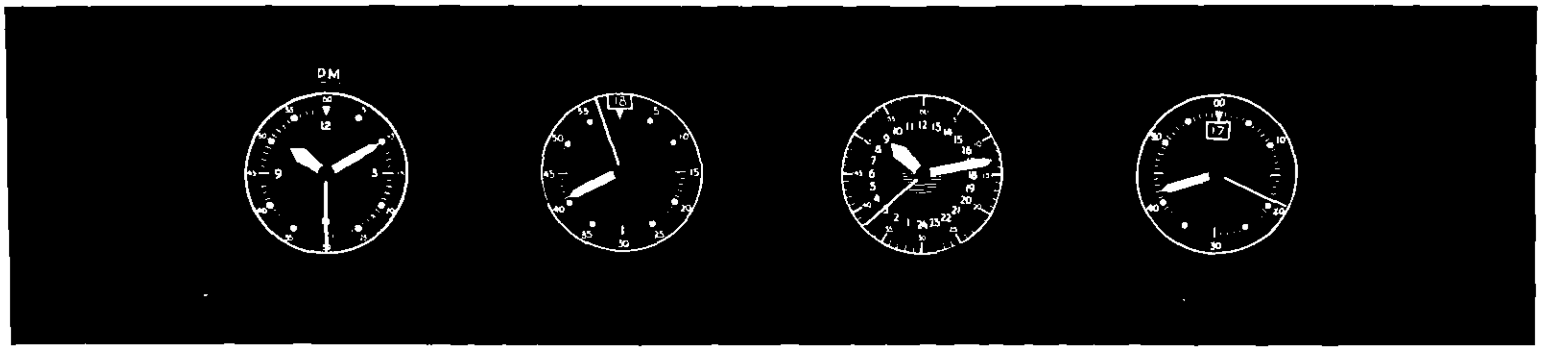
Attention was focused first upon various dial designs and design characteristics. The intention was to include in the test a sufficient number of dials and a variety of design characteristics which together would offer the probability that the investigation could explore the subject with a reasonable degree of completeness.

The design of a counter-pointer dial came first. Since this clock dial would be used by the crewmember only while flying, it was necessary that there be as little difference as possible between the manner in which this dial was read and the manner in which the conventional twelve hour dial, to which he might be accustomed, would be read. Accordingly, it was decided to retain the normal minute-second scale and minute hand. An examination of other scale designs revealed that they generally had the minute graduations at the outer edge of the dial with the appropriate numerals closer to the center. This design requires that the minute hand successively obscure all numerals in its sweep around the dial. There seemed to be no reason why the numbers could not be placed at the outer edge with the minute graduations on a smaller, adjacent circle. This was done and a minute hand just long enough to reach the inner edge of the graduation marks was provided. Numbers were placed at each five minute interval because Grether's study showed this to be desirable. All numerals used on the test dials conformed, within hand drawing limits, to the specifications outlined in Army-Navy Aeronautical Design Standard, number AND 10400.

The placement of the hour counter window was then considered. It could be placed either on the dial or off the dial. A location outside of the normal circular limits of the dial face seemed to be unreasonable. The extra time and effort required to visually locate the separated counter and pointer might be so great as to cancel any gains. The engineering implications of a change in the shape of the total instrument were also considered to be opposed to such a design. Hence, location of the counter somewhere on the face of the dial seemed desirable. There were two basic possibilities: The counter could be placed outside the area swept by the minute hand or it could be placed somewhere on the dial area swept by the minute hand. It was reasoned that the most logical location would be that one which was most visible. Obviously, this was beyond the tip of the minute hand. The counter was placed, finally, at the top edge of the dial. Possibly it would have been equally as effective, or more effective, had it been placed at any dial edge position other than the top. It seemed, however, that the top center position was most reasonable. Such was the development on the counter-pointer dial as illustrated in Figure 1-B.

At this point, the thought occurred that confusion might result from the location of the hour counter on the same circle that contained the minute-second numerals. The only other position possible was in the area covered by the minute hand, but it was considered desirable to use this other position to provide a comparison with the first design. Again, there were many possibilities for specific location and the most reasonable was chosen as being on the vertical center line just below the minute graduations. Since the test now had two counter-pointer dial designs, it was decided to further modify the second design by placing minute numerals at ten minute intervals. This would provide a comparison between the two types of numbering and the results could be checked by Grether's findings. The final form of this second dial design is as shown in Figure 1-D.

It was felt that a design in common use on United States Air Force aircraft should be included in the test for comparison purposes. Such a design is Figure 1-A. It was reproduced exactly as shown on the manufacturer's drawing.



A B C D

FIGURE 1

Dial Designs Tested

The fourth dial design was the twenty-four hour scale design found by Grether[12] to be superior to the twelve hour scales in his test. The only changes were the color background and the addition of the second hand. This design is illustrated in Figure 1-C.

The problem of whether or not to include the second hand in the presentation of each dial was carefully considered. Grether apparently did not include it and there are many valid reasons for the exclusion. First, it is used to a lesser extent than are the hour and minute hands. Second, it is possible that a measure of the interpretability of a clock dial without a second hand would be equally accurate for the same dial with a second hand. Third, it is impossible to present, in a printed type of test, the proper relationship between the relatively static hour and minute hands and the moving second hand. On an actual clock dial, the rapidly moving second hand immediately provides the observer with a visual clue to its identity. Thus, in addition to length, width and color of the second hand, the movement differentiates it from the other hands and tends to prevent confusion. Yet, in opposition to these reasons, there are some sound reasons for inclusion of the hand. First, is the simple fact that the hand is part of the normal clock dial and is actually used.

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[12] W. F. Grether, Designing Clock Dials for Greatest Speed and Accuracy of Reading in the Military (24 hour) Time System, USAF Aero Medical Laboratory Memorandum Reports, #694-8, 21 October 1946, pp. 9 and 10.

Perhaps it is not used every time the dial is observed, but any use which justified its inclusion on an actual dial would also operate to justify its use in the test situation. Second, the only way to be sure that the exclusion of the hand was unimportant would be to test the dial under both conditions. Without such factual evidence it seems best to include the second hand. Third, to correctly portray the second hand would require a test apparatus in which the hands were in motion. However, in a static situation, such as a printed test, the second hand probably could be presented in such a manner that confusion between it and the other hands would be minimized. Such a presentation was attempted in this investigation. To enable the second hand to be more readily recognized in a static situation, it was decided to place it, in every case, approximately opposite the bisector of the angle between the minute and hour hands on settings of the twelve hour dial, A. At any rate, the fact that the second hand is part of the actual dial seems to be enough reason to include it, as accurately as possible, in the test situation. Anything less would destroy the similarity between the test and the actual dials and might invalidate the results. Clearly, such could not be tolerated. Accordingly, it was decided to include the second hand in this test.

The four dials, samples of which are shown in Figure 1, constitute the basis of the investigation. Many other dial designs could have been considered, but limitations of time prohibited their inclusion. Further, the investigation was an attempt to establish a fundamental comparison between basic designs; namely, comparison of the counter-pointer clock dial design with a conventional and a proposed design. With this relationship established, further investigation could be conducted with variations of the basic designs.

With the establishment of the test designs completed, attention turned to consideration of the time settings for the test. At once two distinct possibilities were evident. First, the settings for individual dial designs could be different from each other. Second, the same settings could be used for each design. Kappauf[13] points out that for general effects the first alternative may be satisfactory but that some designs show specific types of errors and, therefore, a comparison of dials might not be valid without identical settings. This condition exists with respect to the dial designs considered here. Each design has certain but different settings that are more difficult to read. For this reason it was decided to use the same settings in testing each dial design. To prevent detection of identical readings by the subjects, two devices were used. First, the total number of settings used was large

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[13] Kappauf, op. cit., p. 11.

enough to minimize the probability of recognition. Second, the settings were not made exactly identical. The values assigned to the seconds were varied a maximum of plus or minus two. In this way the subject was forced to read the entire setting to obtain the correct value and yet it was considered unlikely that the small difference in seconds would materially alter the ease or difficulty of reading that particular setting.

The twenty specific settings finally selected for the test (Appendix A) were based on dial design, A, the conventional twelve hour scale dial. This was done because dial A is the present standard; everything else must necessarily be compared with it. Further, it required more mental calculation than did the other three designs. It was reasoned that any series which would equalize the difficulty of readings on dial A would not, at least, increase the reading difficulty on the other designs.

The dial was divided into quadrants starting at the seven and one-half minute point and at each fifteen minute interval thereafter. The twenty test settings were then apportioned as follows: Each of the twenty represented a different hour of the day. A setting of the hour and second hands in the same quadrant was used twice for each quadrant. This accounted for eight settings. Three settings were used where the hour hand remained in one quadrant while the minute hand was placed successively in the other three quadrants. Repeating this last procedure for all quadrants provided the remainder of the settings. In addition, the number of settings on an even five minute marker or on an even hour was limited approximately in proportion to the total possible even five minute and the total possible even hour settings. The second hand was set, in every case, approximately opposite to the bisector of the angle between the minute and second hands.

III. THE APPARATUS

The next thing considered was the apparatus for the proper presentation of the test dials. This could take any one of many forms. The dials could be placed on actual, operating clocks, they could be mockups with moveable hands or they could be printed in some manner. Further, they could be presented singly or in groups. They could be presented in a tachistiscope or without a time limit. They could be presented on a printed page or on viewing cards. The subject might be required to record the results with pencil and paper, or to read the values aloud. All of these various arrangements have their individual merits. The guiding thought in the final selection of the method used here was to achieve as great a similarity as possible between the test situation and the actual situation confronted by an aircrew member facing his instrument panel. This principle ruled out the tachistiscope, the printed page, and the pencil and paper. An actual clock, although realistic enough, was eliminated because of difficulties in setting various times into it rapidly and accurately. A subject could read a dial with no more accuracy than that with which it was set. To avoid possible sources of test error here, it was decided to use a method whereby all settings were previously and permanently arranged. This line of reasoning finally led to the use of test cards on which the various dial settings had been photostated with white lines on a black background. The photostats were reduced from large mockups to the exact size of a commonly used aircraft clock, 1 7/8" diameter. Since it is normal for an individual to use, and become accustomed to, one design, each test design was presented completely and successively. The actual make up of the test cards was in three parts for each design. Thus there were twelve test cards. Each design series contained one card with one dial, which was used for the purpose of explaining the features of that particular design to the subject. An example of one of the view cards is illustrated in Figure 2. The setting used was selected at random. The second card in each design series contained four different dial settings and was used for the purpose of allowing the subject to obtain practice and achieve a measure of familiarity with that design. An example of one of the practice cards is illustrated in Figure 3. The settings used were selected

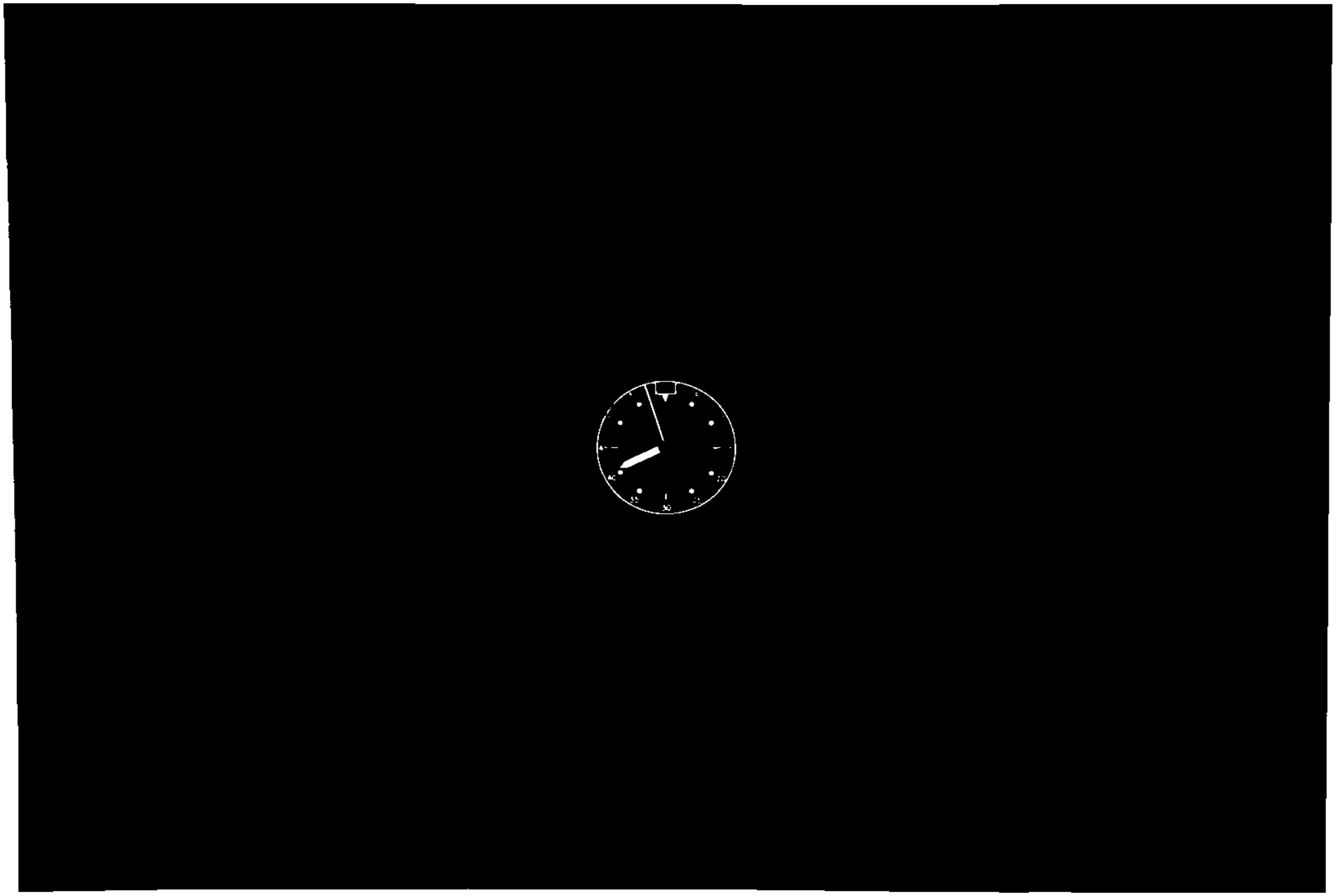

FIGURE 2

Sample Card, Dial B

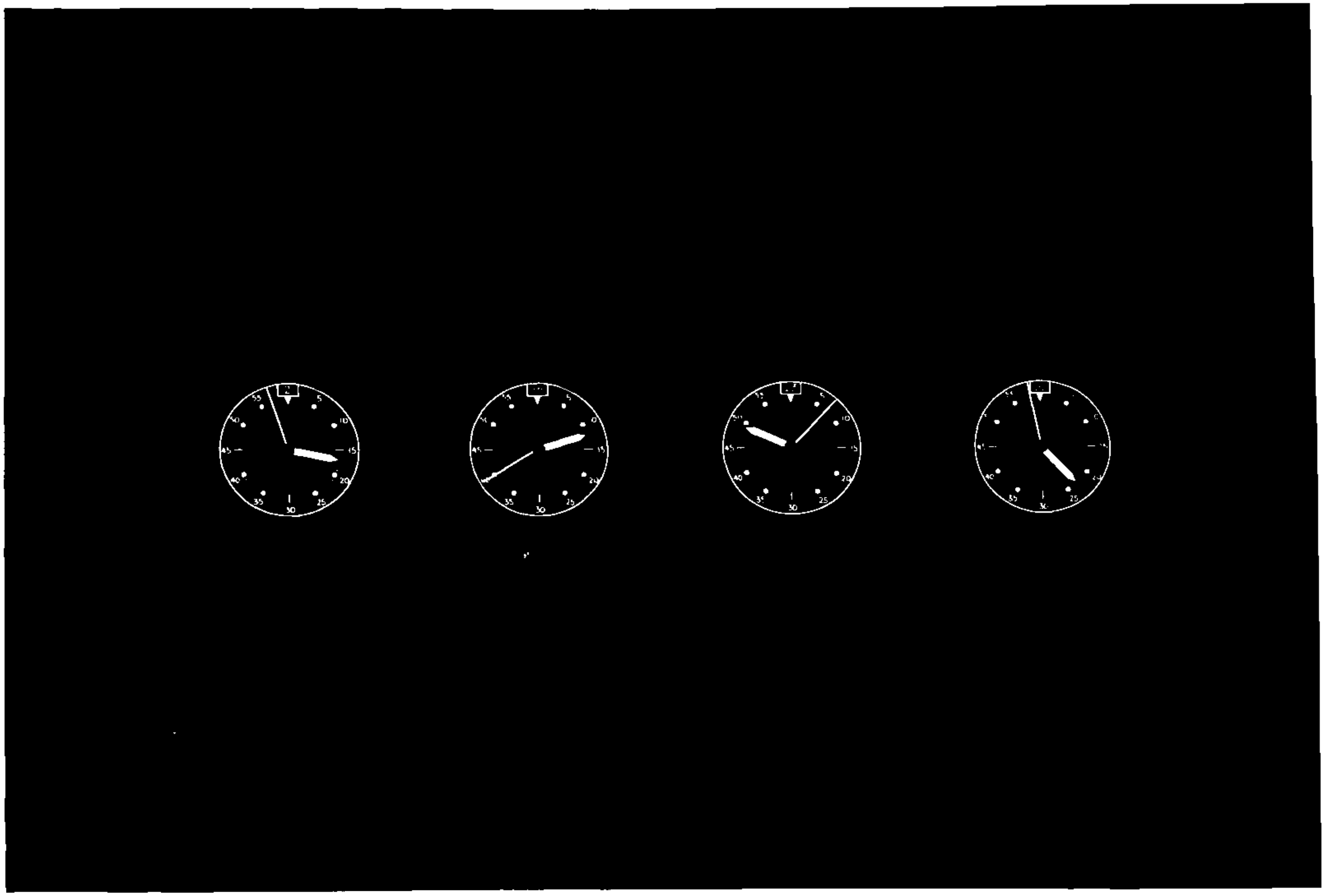

FIGURE 3

Practice Card, Dial B

at random or to illustrate some particular feature of the dial. The short practice period before the test on each design was thought to be desirable in view of the fact that Kappauf[14] found practice effects to be important. Further, the short practice period, it was thought, would tend to reduce the factor of learning in the subsequent test readings and would allow a true measure of the interpretability of the dial design. The third card in each design series was the test card containing twenty dial settings. Its purpose was to obtain speed and accuracy readings. An example of one of the test cards is illustrated in Figure 4. It can be seen that the intention of simulating an instrument panel is achieved. The subject is required to successively select dials from a large group. This approximates the actual situation.

The method of presenting these cards to the subject was to insert them in the viewing box, illustrated in Figure 5. The subject was seated in front of the viewing box so that the reading distance was approximately twenty-eight inches. This conforms closely to the standard for visual research and is a fair average of the situation encountered in an airplane. The box contained its own constant illumination which provided a minimum of thirteen

[14] Kappauf, op. cit., p. 40.

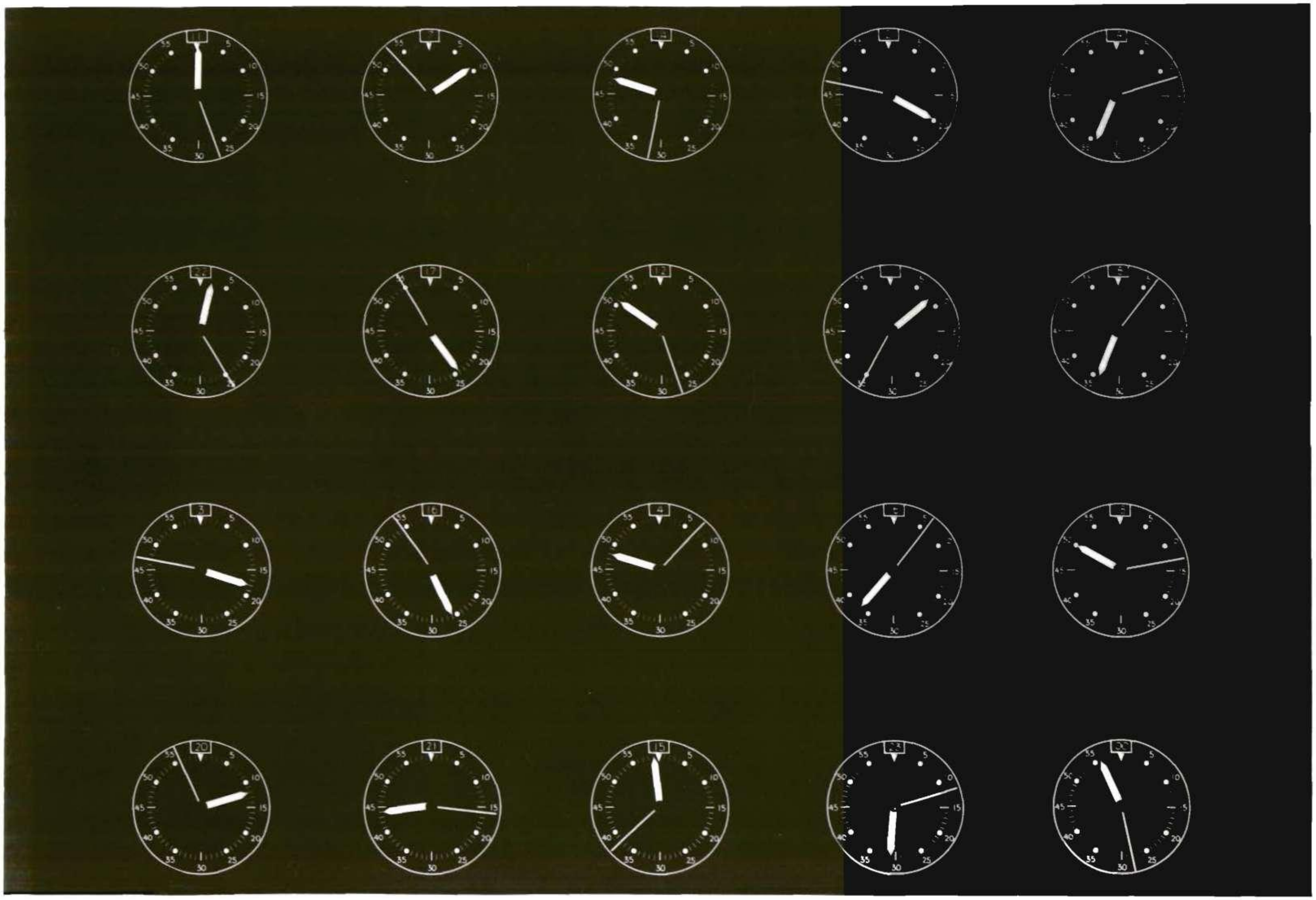

FIGURE 4

Test Card, Dial B

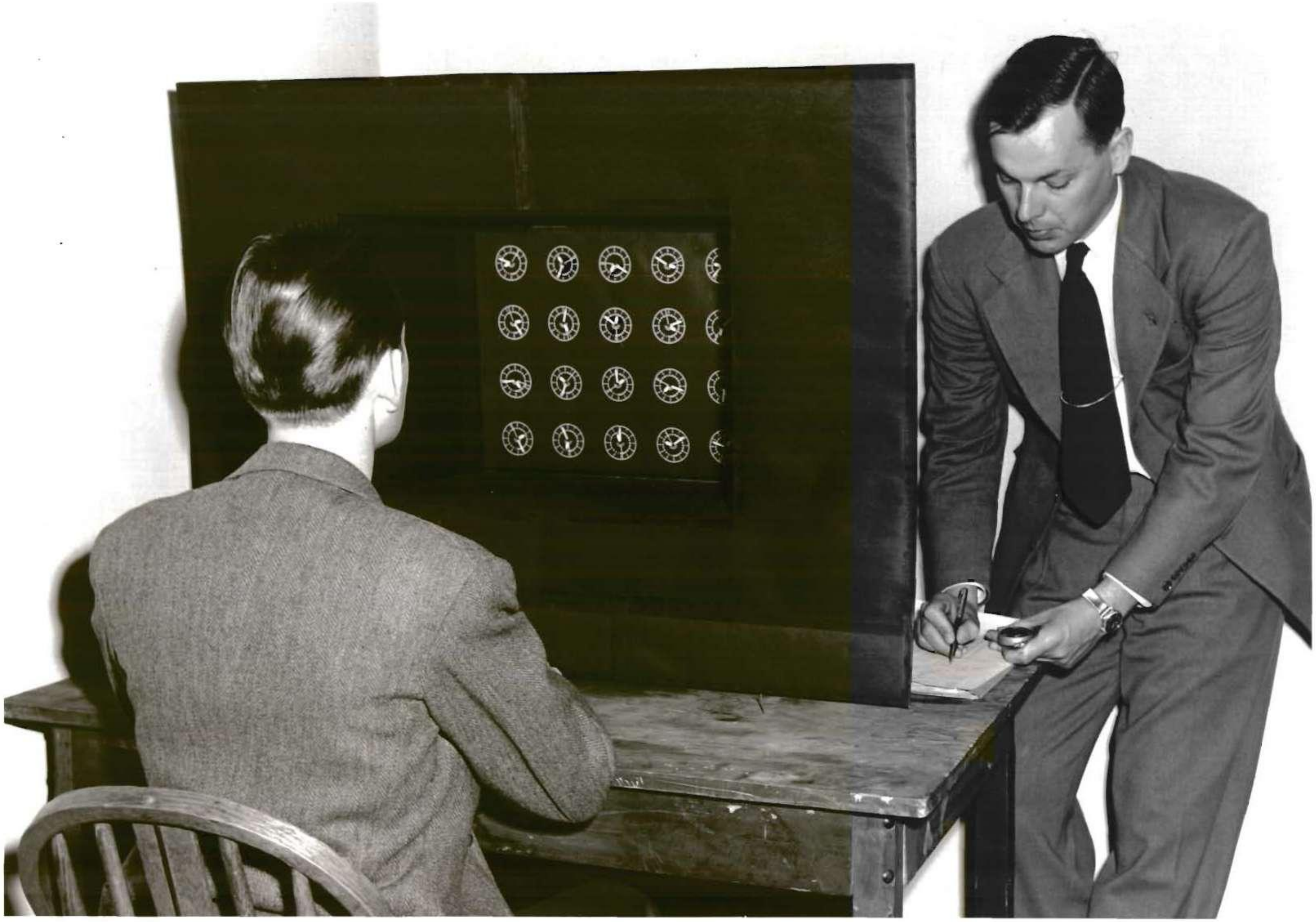

FIGURE 5

Test Apparatus

and a maximum of forty foot candles on various sections of the test card. This is above the minimum recommended for visual tasks of this type.

Some thought was given to fixing the position of the subject's head to avoid a variation in reading distance while he participated in the test. Such a procedure was rejected for the following reasons: First, the test was not one of legibility, but rather one of interpretability. An error in interpretation might be made even with perfect legibility. Second, the natural situation for the reader is to be free to move forward for a closer look, if such is thought to be desirable. Since the test would be scored on speed and accuracy, the extra time required for closer scrutiny of a dial would be reflected in the score along with any additional accuracy. Generally, the position of the subject with respect to the test dials would be constant within narrow limits. Such a condition was believed to be satisfactory for purposes of this investigation.

IV. THE PROCEDURE

The procedure used in conducting each test was to check the subject's vision by means of a Snellen chart and then to seat him before the view box, as shown in Figure 5. An explanation of the test objectives and general procedures was read to the subject from a prepared statement. Then the sample card for the first dial design was placed in the view box and the characteristics of that design were explained to the subject. When the test administrator was satisfied that the subject understood the design, the practice card of four dial settings was presented. The subject read aloud the settings of these dials, after which any other questions were answered. The test card was then presented and the subject read aloud the settings as rapidly and as accurately as possible. On a data sheet, the test administrator checked correct responses and recorded the actual response when an error was made. He also timed the subject in seconds from start to finish for the twenty settings. This procedure was then repeated for the three other designs. To minimize any practice or fatigue effects, the sequence of presenting the four dial design tests was varied from subject to subject in such a manner that, in the final analysis, each dial design was presented in the first, second, third, and fourth positions an approximately equal number of times.

V. THE SUBJECTS

The eighty-five subjects were all volunteer, male students attending an engineering college. They were, generally, third, fourth, and fifth year men, although a few underclassmen were included. These subjects were divided into two groups: those with military pilot experience, and those without such experience. Since the investigation was one of testing clock dials for aviation use, it was believed essential to include a group who were experienced in that field. The group of non-pilots was selected because it was believed that they would not have had experience in reading instrument dials. It was also assumed that this group would be inexperienced with the twenty-four hour time system. This proved to be partially incorrect since many of these men had such experience in the military services other than aviation. However, the results for this group should approximate the results expected of a group attempting to learn to use the aviation clock dial.

All subjects were checked for normal vision in order to exclude those who, because of visual defects, would read more slowly or less accurately. Thirty-six pilots and forty-nine non-pilots were tested. The detailed results of the tests are contained in the next chapter.

CHAPTER IV

RESULTS

SUMMARY

Thirty-six military pilots and forty-nine non-pilots read twenty settings on each of four different clock dial designs as rapidly and as accurately as possible. Figure 6 summarizes, generally, the results of the investigation. Inspection of Figure 6 reveals that, in every case, the subjects with pilot experience excelled, by approximately the same percentage, over those without such experience. On the basis of averages, the most rapidly read dial was dial B, an original counter-pointer design. The dial which was read slowest, on the average, was dial A, the conventional twelve hour scale design. This relationship was repeated with respect to reading accuracy. The most accurate was B; the least accurate was A.

A further comparison was made showing the relationship of any one dial to another within the categories of pilots - speed or accuracy of non-pilots - speed or accuracy. Thus any two dials read by pilots or read by non-pilots were compared for speed or for accuracy. The comparison was made on the basis of the dial preference of the subject. For example, in comparing the speed of pilots on dials A and B, a subject who read A in less time than B was considered to prefer A. (In this comparison no account was taken of the

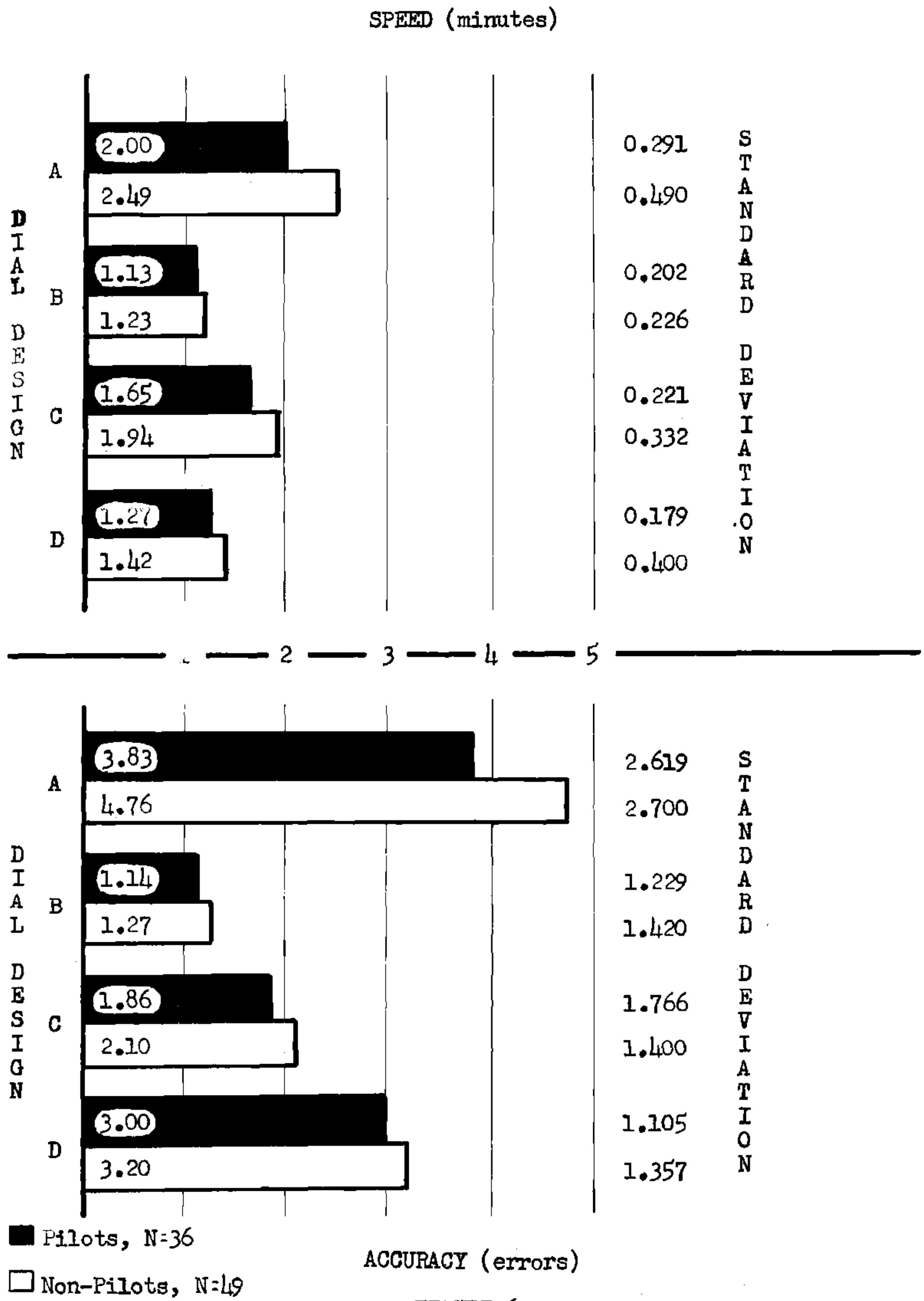

FIGURE 6

SPEED AND ACCURACY MEANS, PILOTS AND NON-PILOTS, TWENTY SETTINGS magnitude of preference.) A tabulation was made of this preference for all subjects and the totals were expressed as percentages. Figure 7 is a tabulation of dial preference by percent of subjects. The difference between any two dials is significant to the five percent level of confidence for all comparisons except those between A-D and B-C, errors, both pilots and non pilots. The significance of the five percent level of confidence is that, within the limits of probability, the differences occurring would be due to chance only five times out of every one-hundred trials. Conversely, ninety-five times out of one hundred the difference could be attributed to some real difference in the design of the dials, the apparatus, the procedure,or the subjects.

The frequency distributions of time and errors, Appendix B, show an approximately normal distribution for time frequencies. Error frequencies show distributions varying from near normal to a reverse "J" type of curve. Because of the deviation from normality of certain of the frequency distributions, the Chi square test of significance was utilized,[15] Appendix C. In addition, the significance of those frequencies that approached normality were checked by

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[15]Garrett, H. E., Statistics in Psychology and Education (third edition; New York: Longmans, Green and Company, 1947), p. 250.

ERRORS
% Pilots Preferring Dial

To Dial	A	B	C	D
A	-	78	78	50
B	22	-	50	17
C	22	50	-	17
D	50	83	83	-

TIME
% Pilots Preferring Dial

To Dial	A	B	C	D
A	-	100	86	100
B	0	-	0	19
C	14	100	-	100
D	0	81	0	-

N = 36 Note: Values less than 33 or greater than 67 are significant to the 5% level of confidence.

ERRORS
% Non-Pilots Preferring Dial

To Dial	A	B	C	D
A	-	94	80	63
B	6	-	43	12
C	20	57	-	14
D	37	88	86	-

TIME
% Non-Pilots Preferring Dial

To Dial	A	B	C	D
A	-	100	100	100
B	0	-	0	18
C	0	100	-	100
D	0	82	0	-

N = 49 Note: Values less than 36 or greater than 64 are significant to the 5% level of confidence.

FIGURE 7

Dial Preference of Subjects

means of the "t" test,[16] Appendix C. All check calculations substantiated the results obtained in the original calculations.

The frequency occurrence of specific errors is shown in Appendix D. Inspection of the tabulation of errors by dial setting discloses the fact that certain settings were particularly troublesome on one design while the same setting offered no trouble on other designs. Note particularly, numbers one, fifteen,and twenty, which were frequently missed on dial A and were infrequently missed on the other dial designs. Note also numbers two, six, and sixteen. The hour, minute, and second totals for all dials indicate that errors on minutes and seconds are roughly the same on all dials while a large variation is shown in the totals for the hour errors between the different designs.

The tabulation of magnitude of errors shows that errors in the hour setting of dials A and C were predominantly of the one hour error type and that the hour errors of dial D were all of a miscellaneous type. Minute and second errors were distributed fairly evenly between magnitudes of one, five, and miscellaneous.

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[16] Ibid, p. 204.

II. DISCUSSION

A counter-pointer clock dial design is significantly better in terms of speed than either the presently used twelve hour scale design or the twenty-four hour design found best by Grether. In terms of accuracy, the counter-pointer type is significantly better than the twelve hour scale design, but is not significantly better than Grether's twenty-four hour scale design.

There was no substantiation of Grether's finding that numerals at each five minute interval decreased minute errors. Dial B had numerals at each five minute/second interval, while dial D had numerals at each ten minute/second interval. No appreciable difference was noted in the minute or second errors between these two designs.

Three specific details of design produced marked difficulty of interpretation. First, the twelve hour scale of dial A produced numerous hour errors, and it may be fairly presumed that the required mental calculation caused the subjects to read this dial more slowly than the other three. Second, the small distance separating the hour numerals on dial C caused misinterpretation and frequent hour errors. This may have been due to the fact that the hour hand progressively approached the next higher hour numeral as the minute hand swept the dial. During the latter portion of any hour the hour hand points almost directly at the next higher numeral. Thus, to read correctly, the subject must not only observe the position of the hour hand but must also observe and give due weight to the position of the minute hand. Third, the counter window of dial D was so placed that it was obscured part of the time by the minute hand. Naturally, when the minute hand partially or completely covered the hour counter, it was difficult or impossible to accurately determine the hour.

All subjects expressed the opinion that dial B was most satisfactory from their personal point of view. Supporting this is the observation of the writer that explanation of how to read a particular dial design was much simpler on dial B than on any other design. Even though the subject had no previous experience in reading time in the twenty-four hour system, he was able to immediately and rapidly read dial B.

It seems clear that in terms of preference and performance the counter-pointer dial B is the superior design.

III. CONCLUSIONS

1. A counter-pointer type of dial is significantly better than a multiple pointer dial for speed of reading.
2. The counter-pointer dial, B, is significantly better than the multiple pointer dial, A, for accuracy of reading.

3. The counter-pointer dial, B, is equivalent to the multiple pointer dial, C, for accuracy of reading.
4. Multiple pointer type dials are subject to frequent hour errors.
5. Counter-pointer type dials rarely produce hour errors.
6. There is no significant advantage in placing minute numerals at intervals of five minutes. Numerals placed at ten minute intervals produce equivalent results.
7. Placement of a counter window, as in dial B, is significantly better than placement as in dial D, for accuracy of reading.

IV. SUGGESTIONS FOR FURTHER RESEARCH

1. Investigate to determine the optimum size of the counter window on a counter-pointer dial.
2. Investigate various positions, other than on the top center line, for the counter window on a counter-pointer dial.
3. Investigate, under conditions of lighting similar to that encountered by the crewmember on a night flight, performance on the four dial designs tested in this study.

4. Investigate, under conditions of a tachistoscopic presentation, performance on the four dial designs tested in this study.
5. Investigate, by using many more than twenty settings, performance on the four dial designs tested in this study.
6. Investigate, by using actual, operating, clock dials, performance on the four dial designs tested in this study.

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A P P E N D I X

APPENDIX A

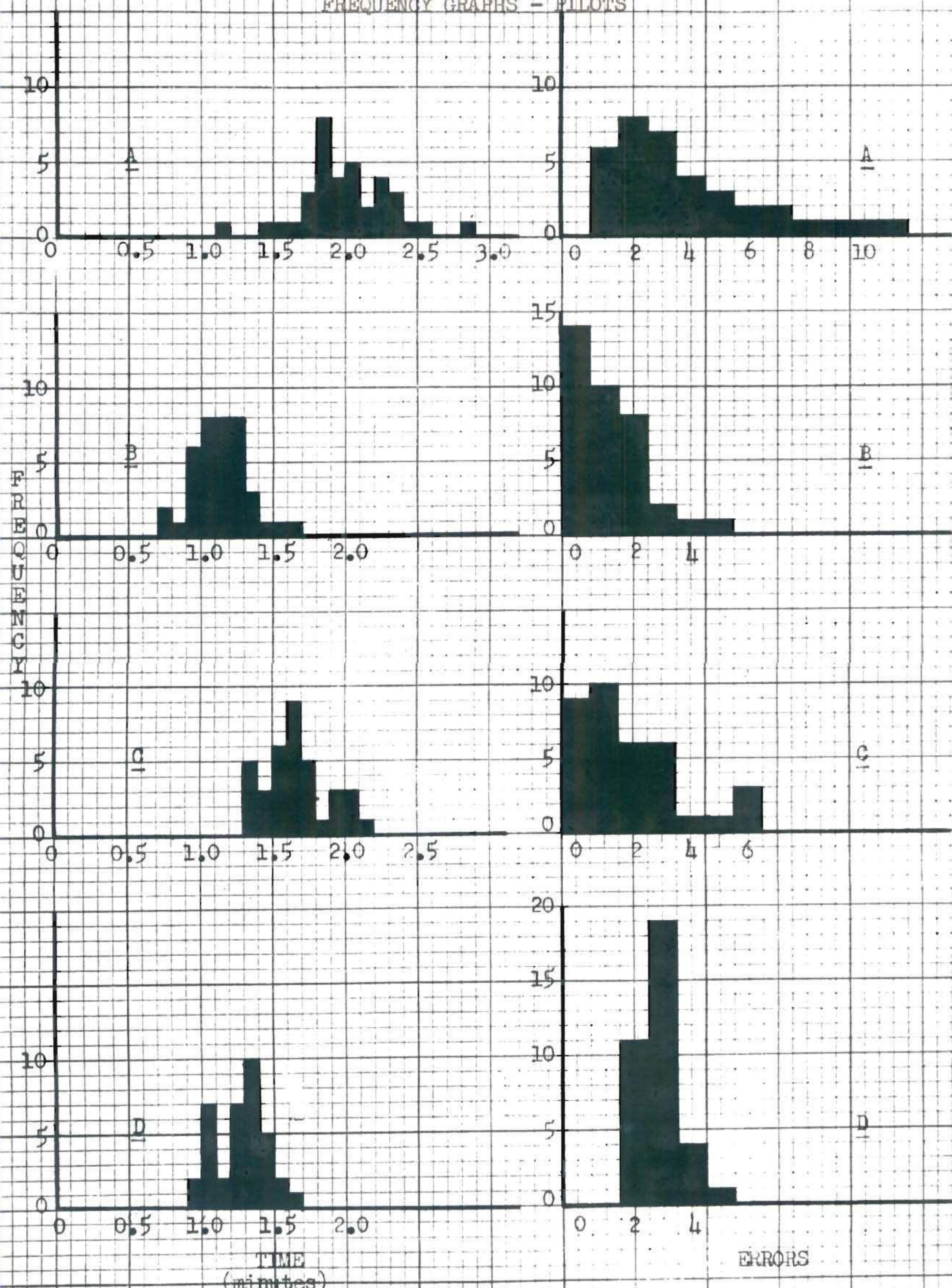
DIAL SETTINGS TESTED

DIAL DESIGN

	A	B	C	D
1	00 56 30	11 00 27	04 48 06	22 02 26
2	15 59 40	07 09 53	09 34 11	04 48 04
3	01 08 37	14 48 32	02 20 46	18 50 10
4	23 31 14	02 20 47	18 50 12	20 12 57
5	08 34 08	09 34 12	06 37 05	09 34 09
6	11 00 28	22 02 25	17 24 57	06 37 03
7	03 18 48	17 24 55	22 02 27	17 24 56
8	07 09 54	12 51 27	12 51 29	21 44 17
9	16 26 55	01 08 35	20 12 58	02 20 44
10	14 48 33	08 34 06	01 08 36	14 48 31
11	04 48 05	03 18 47	21 44 18	11 00 26
12	02 20 45	16 26 54	08 34 07	12 51 28
13	06 37 04	04 48 07	15 59 39	16 26 53
14	09 34 10	06 37 06	03 18 49	23 31 15
15	18 50 11	18 50 13	23 31 13	03 18 46
16	22 02 28	20 12 56	16 26 56	15 59 41
17	20 12 59	21 44 16	00 56 29	07 09 52
18	17 24 58	15 59 38	11 00 29	01 08 38
19	21 44 19	23 31 12	07 09 55	00 56 31
20	12 51 30	00 56 28	14 48 34	08 34 09

APPENDIX B1

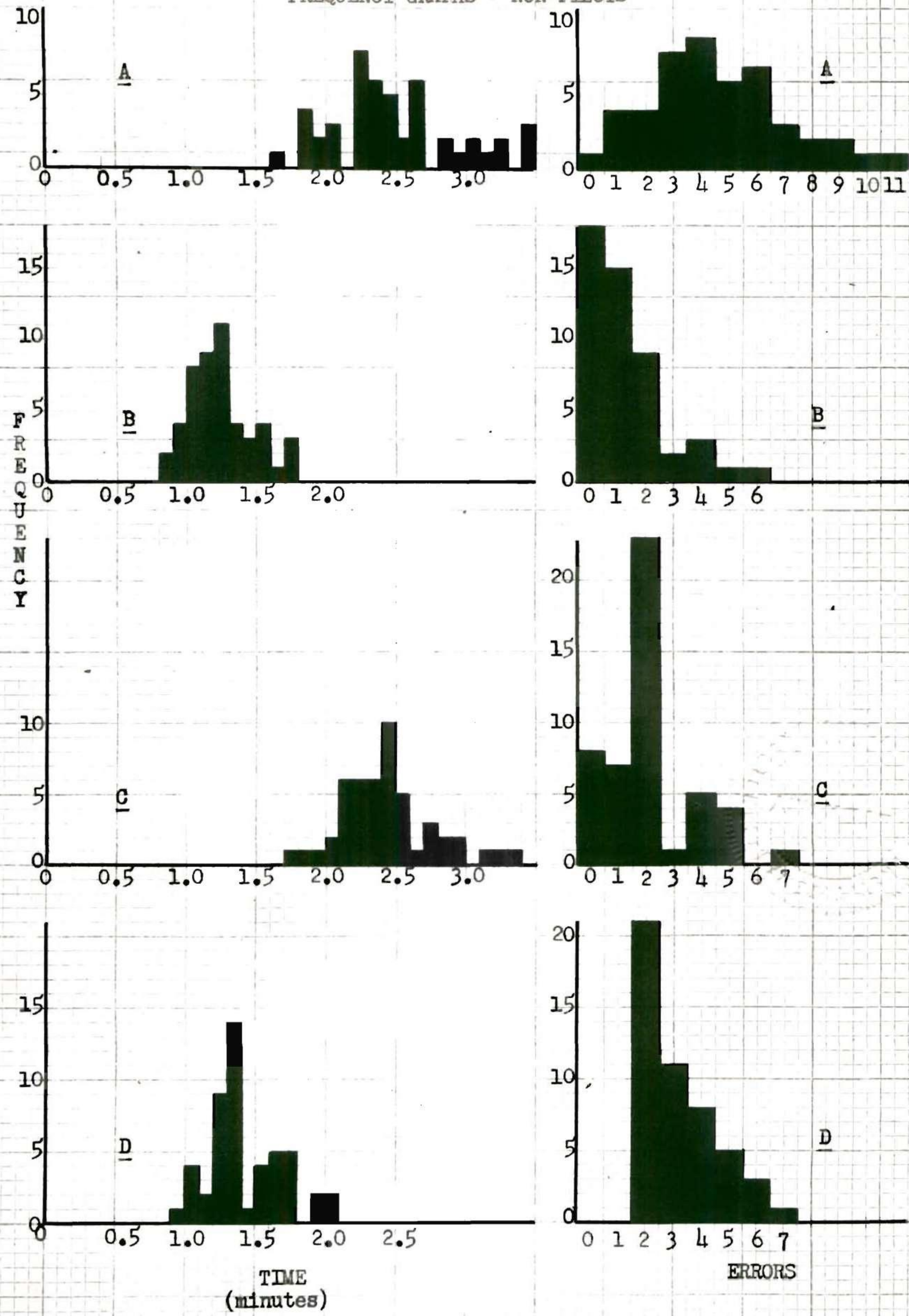
FREQUENCY GRAPHS - PILOTS



Note: N = 36

APPENDIX B2

FREQUENCY GRAPHS - NON-PILOTS



Note: N = 49

APPENDIX C1

SAMPLE CALCULATIONS

I. Significance of differences by Chi square method.

EXAMPLE: Compare dials A and C for time - Pilots.

X^2 = Chi square

f_o = Frequency observed

f_e = Frequency expected

$$X^2 = \Sigma \left[\frac{(f_o - f_e)}{f_e} \right]$$

	For Dial		
	A	B	
$f_o\%$	14	86	100%
$f_e\%$	50	50	100%
$f_o - f_e =$	20	20	
$(f_o - f_e)^2 =$	400	400	

$$X^2 = \frac{2(400)}{50} \times \frac{36}{100} = 5.92$$

From X^2 table, p 242 Garrett, significance is at the 2% level.

APPENDIX C2

SAMPLE CALCULATIONS

II. Significance of differences by "t" method.

EXAMPLE: Compare dials A and C for time - Pilots.

$\bar{X}$ = Mean

ΣX^2 = Sum of deviations from mean, squared

N = Number of subjects

$$t = \frac{\bar{X}_A - \bar{X}_C}{\left[\left(\frac{x_A^2 + x_C^2}{N_A - 1 + N_C - 1}\right)\left(\frac{N_A + N_C}{N_A N_C}\right)\right]^{\frac{1}{2}}}$$

$$t = \frac{2.00 - 1.65}{\left[\left(\frac{3.05 + 1.75}{36 - 1 + 36 - 1}\right)\left(\frac{36 + 36}{36 \times 36}\right)\right]^{\frac{1}{2}}}$$

$$t = \frac{2.00 - 165}{\left(\frac{4.80}{1260}\right)^{\frac{1}{2}}} = \frac{0.35}{0.0617} = 5.67$$

From $\underline{t}$ table, p 190 Garrett, significance is at the 1% level.

APPENDIX D1

TYPE OF ERRORS - PILOTS

DIAL DESIGN

	A				B				C				D			
	H*	M*	S*	T*	H	M	S	T	H	M	S	T	H	M	S	T
1	30	4	1	35		2		2	8	1		9		1	2	3
2	13			13		1		1	3		1	4	36			36
3	3	5	1	9		3	3	6	2	3	1	6		1	1	2
4	1	1	1	3					1		3	4				
5		2		2		2	2	4					1			1
6			2	2							1	1	36			36
7		2		2		1	1	2		2	1	3		1		1
8	3	1	3	7		1	2	3		3	4	7			1	1
9	4			4		2	2	4		1		1		2	7	9
10	5	1		6		3	2	5						2		2
11	2	1		3		1	2	3	2	3		5		1	1	2
12	1	1		2		2		2		1		1				
13		4	1	5		1		1		1		1		1		1
14																
15	9	1	1	11			3	3	2	2		4				
16	6	1	1	8					8	1	1	10				
17	3	1		4							3	3		2	3	5
18	2	2	0	4		1		1			1	1		1	2	3
19	6	1	1	8		2		2	1	2	1	4		1		1
20	9	2		11		2		2	1		2	3		1	1	2
Total	97	30	12	139	0	24	17	41	28	20	19	67	73	14	18	105

* H, M, S, and T are, respectively, Hour, Minute, Second and Total. Settings 1 through 20, A, B, C, and D are corresponding dial settings keyed to column A, Appendix A. Example: No. 1 is 00 56 30 for A, B, C and D. No. 2 is 15 59 40 for all designs etc. — N = 36.

APPENDIX D2

TYPE OF ERRORS - NON-PILOTS

DIAL DESIGN

	A				B				C				D			
	H*	M*	S*	T*	H	M	S	T	H	M	S	T	H	M	S	T
1	39	2		41		2	2	4	7	3	2	12		1	1	2
2	25			25		4	4	8	2	1		3	49	4		53
3	3	13	6	22		2	2	4	3	4	1	8		2	1	3
4	3		5	8					1	1	3	5			1	1
5		4	1	5		1	1	2		1	1	2		3	2	5
6	1		4	5		4		4	1	1		2	49		1	50
7		5		5		1		1		3	1	4		4		4
8	2	1	4	7			2	2		1	7	8			1	1
9	1	1	3	5		2	2	4		2	1	3		2	3	5
10	6	3	6	15		3	1	4		3		3		2		2
11	11	2		13	1	1		2	2	3		5		1	1	2
12	4			4		2		2	1	1		2			1	1
13	1	1	2	4		3	2	5		1	1	2		5		5
14		3		3		1	1	2	1	1		2		2	1	3
15	14			14	1		5	6	3	4		7				
16	6	1	2	9		3		3	19			19				
17		2		2			1	1			1	1		2	7	9
18	2	2		4		1	1	2		1	4	5		1	1	2
19	6	3	1	10		1		1		3	2	5			6	6
20	23	3	1	27		5		5		3	1	4		3		3
Total	147	46	35	228	2	36	24	62	40	37	25	102	98	32	27	157

*H, M, S and T are, respectively, Hour, Minute, Second and Total. Settings 1 through 20, A, B, C and D are corresponding dial settings keyed to column A, Appendix A. Example: No. 1 is 00 56 30 for A, B, C and D. No. 2 is 15 59 40 for all designs, etc. -- N = 49.

APPENDIX D3

MAGNITUDE OF ERRORS - PILOTS AND NON-PILOTS

		PILOTS N = 36				NON-PILOTS N = 49			
	Magnitude of error	A	B	C	D	A	B	C	D
Hour	1	59		26		104		36	
	12	17		2		21		2	
	Other	21			73	22	2	2	98
	Total	97		28	73	147	2	40	98
Minute	1	8	7	12	4	24	16	9	7
	5	11	7	3	6	9	9	12	12
	Other	11	10	5	4	13	10	16	13
	Total	30	24	20	14	46	35	37	32
Second	1	5	3	7	3	12	9	4	8
	5	3	7	7	8	10	8	13	8
	Other	4	7	5	7	13	8	8	11
	Total	12	17	19	18	35	25	25	27
	Sum Total	139	41	67	105	228	62	102	157

Note: Direction of errors was disregarded.